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14. ABSTRACT The objective of this task is to compile a list of materials testing capabilities suitable for testing the materials development for liquid rocket engines by the JANNAF liquid propulsion community in USA. Information has been collected on the materials testing capabilities in some of the commercial testing laboratories, academic research and development institutes, and government organizations; it has been compiled, and has been listed in Tables I, II and III, respectively. The ASTM standards for most of the materials properties testing have been listed in Table IV. The testing capabilities include mechanical properties test, chemical analysis, metallurgical evaluation, non-destructive evaluation, thermal properties measurement, and other related properties testing. The examples of mechanical properties test are yield strength, hardness, high cycle fatigue, low cycle fatigue, creep, Young's modulus, and Poisson's ratio. The thermal properties of materials include, but are not limited to, coefficient of thermal expansion, specific heat, thermal conductivity, and thermal diffusivity. The metallurgical analysis can survey, but is not limited to, grain size and distribution, fractography examination, phase and defect evaluation. The examples of physical properties are densities and ductility. The chemical analysis can be used to investigate material corrosion resistance, composition, and flammability.					
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## **Materials Testing Capabilities**

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ERC at Edwards Air Force Research laboratory

### **Objective:**

The objective of this task is to compile a list of materials testing capabilities suitable for testing the materials development for liquid rocket engines by the JANNAF liquid propulsion community in USA.

### **Approach:**

Information has been collected on the materials testing capabilities in some of the commercial testing laboratories, academic research and development institutes, and government organizations, has been compiled, and has been listed in Tables I, II, and II, respectively. The ASTM standards for most of the materials properties testing have been listed in Table IV. The testing capabilities include mechanical properties test, chemical analysis, metallurgical evaluation, non-destructive evaluation, thermal properties measurement, and other related properties testing. The examples of mechanical properties test are yield strength, hardness, high cycle fatigue, low cycle fatigue, creep, Young's modulus, and Poisson's ratio. The thermal properties of materials include, but are not limited to, coefficient of thermal expansion, specific heat, thermal conductivity, and thermal diffusivity. The metallurgical analysis can survey, but not limited to, grain size and distribution, fractography examination, phase and defect evaluation. The examples of physical properties are densities and ductility. The chemical analysis can be used to investigate material corrosion resistance, composition, and flammability.

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Table I: Some commercial laboratories provided materials properties testing.

Laboratory	Phone #	Fax #	Address	website	M-E	C-A	M-E	NDE	T-P	Others
Accutek Testing Lab	513-9844112	513-9848258	3701 Port Union Rd, Fairfield, OH 45014	accutektesting.com	X		X			Welder qualification
Aero Prep	513-4698300	513-4691020	11584 Goldcoast Drive Cincinnati, OH 45249	aeroprepinc.com						Test coupon fabrication
Aerospace Corp	310-3365000	310-3367055	2310 E. El Segundo Blvd, El Segundo, CA 90245	aerospace.org						Particle impact
Balancing Co	937-8989111	937-8986145	898 Center Dr. Vandalia, OH 45377	balco.com						Spin test
BSI	781-9335200	781-9395778	55 Sixth Road, Woburn, MA 01801	Barbourstockwell.com						Spin test
CASE Forensics	425-7755550	425-7750900	23109 55th Ave West, Mountlake Terrace, WA 98043	case4n6.com	X	X	X			
Composite Technology Development (CTD)	303-6640394 x103	303-6640392	2600 Campus Drive, Suite D. Lafayette, PA 15690	ctd-materials.com	x		x			liquid H <sub>2</sub> temperature testing
Dirats	413-5681571	413-5681453	41 Airport Road, Westfield, MA 01086	diratslabs.com	X	X	X			
EAG Lab	408 5303500	408 5303501	810 Kifer Road, Sunnyvale, CA 94086	eaglabs.com		X	X			
Elemental Analysis	859-2545115	859-2545150	2101 Capstone Drive, Suite 110, Lexington, KY 40511	elementalanalysis.com		X				
Fracture System Research	610-9669425	610-9669551	3230 Watermill Drive, Macungie, PA 18062		x					Fracture Mechanics
Innovative Engineering Solutions	951-3047600	951-3047620	26200 Adams Ave. Murrieta, CA 92562	iesnet.com	x					liquid H <sub>2</sub> temperature testing
Laboratory Testing	215-9979080	215-9979511	2331 Topaz Drive, Hatfield, PA 19440	labtesting.com	X	X	X	X		
Mar-Test	513-7712536	513-7712564	1245 Hillsmith Drive, Cincinnati, OH 45241	mar-test.com	X					
Matco Inc	412-7881263		4640 Campbells Run Road, Pittsburgh, PA 15205	matcoinc.com		X				
Materials Evaluation & Engineering	763-4498870	763-4498699	13805 1st Ave North, Suite 400, Plymouth, MN 55441	mee-inc.com		X	X			
Metals Technology Inc.	818-8826414	818-8824490	19801 Nordhoff St. Northridge, CA 91324		x	x	x			
McCrone Associates	630-8877100	630-8877417	850 Pasquinelli Dr, Westmont, IL 60559	mccroneassociates.com		X	X			
Metcut	513-2715100	513-2719511	3980 Rosslyn Drive, Cincinnati, OH 45209	metcut.com	X		X			
NDT Solutions	715-2460433	715-2460466	150 W. First St, New Richmond, WI 54017	ndts.com				X		
NPI	503-2875255	503-2875992	13339 NE Airport Way, Suite 100, Portland, OR 97230	qnpi.com				X		
NSL Analytical	216-4385200	216-4385050	4450 Cranwood Parkway, Cleveland, OH 44128	nslanalytical.com	X	X	X			
QMI	714-9034500	714-9034550	5442 Oceanus Drive, Huntington Beach, CA 92649	qmi-inc.com				X		
Sherry Lab	765-3784101	795-3784107	9301 Innovation Drive, Suite 103, Daleville, IN 47334	sherrylabs.com	X	X	X			
Sonoscan	847-4376400	847-4371550	2149 E. Pratt Blvd., Elk Grove Village, IL 60007	sonoscan.com				X		
Stork Materials Tech	714-8921961	714-8928159	15062 Bolsa Chica Road, Huntingdon Beach, CA 92649	storksmt.com	X	X	X	X		
Test Devices	978-5626017	978-5627939	571 Main Street, Hudson, MA 01749	Testdevices.com						Spin test

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Table I: Some commercial laboratories provided materials properties testing (continued).

Laboratory	Phone #	Fax #	Address	website	M-E	C-A	M-E	NDE	T-P	Others
TPRL	765-4631581	765-4635235	3080 Kent Ave, West Lafayette, IN 47906	tpri.com					X	
Westmorland	724-5373131	724-5373151	221 Westmoreland Drive, Youngstown, PA 15696	wmtr.com	X		X			

**Notes:**

\* M-T: mechanical testing, C-A: chemical analysis, M-E: metallurgical evaluation, T-P: thermal properties.

\* Some (not all) of represented laboratories have provided fee-for-service in the related properties tests.

\* The laboratory list is sequenced according to alphabetical order.

\* Cells marked with "X" mean that the organization has provided fee-for-service for some or all related properties test. Please contact the organizations for the detailed service per the listed information.

Table II: Some laboratories in academia provided materials properties testing.

Organization	Phone	Fax	Address	website	M-T	C-A	M-E	NDE	T-P	Others
Arizona State - AIMS Center	480-9652053	480-7279321	ERC 429, Tempe, AZ 85287-6106	aims.asu.edu	X		X			Multi-axial fatigue
Materials, Georgia Tech	404-8942888	404-8948780	771 Ferst Drive, Atlanta, GA 30332	mse.gatech.edu	X	X	X		X	
Materials, MIT	617-2533300	617-2521175	77 Massachusetts Ave, Cambridge, MA 02139	dmse.mit.edu	X	X	X	X	X	
Materials, Northwestern	847-4913537	847-4917820	2220 Campus Drive, Evanston, IL 60208	matsci.northwestern.edu	X	X	X	X	X	
Materials, Penn State	814-8659857	814-8652917	121 Steidle Bldg, University Park, PA 16802	matse.psu.edu	X	X	X	X	X	
Materials, UCLA	310-8258916	310-2017353	410 Westwood Plaza, Los Angeles, CA 90095	ms.ucla.edu	X	X	X		X	
MRL, Illinois Urbana-Champaign	217-3331370	217-2442278	104 South Goodwin Ave, Urbana, IL 61801	mrl.illinois.edu	X	X	X	X	X	

**Notes:**

- \* M-T: mechanical testing, C-A: chemical analysis, M-E: metallurgical evaluation, T-P: thermal properties.
- \* The listed universities have replied to the survey and provided services for the external based on fee-for-service/pay-per-toll.
- \* Some organizations haven't replied to the task helper yet. Their organization will be added after their information has been received.
- \* Some (not all) represented universities have materials R&D department.
- \* "Materials" means materials department, materials institute, materials college, or materials research laboratory.
- \* Cells marked with "X" mean the organization has provided fee-for-service for some or all related properties test. Contact the organization for the detailed service per the listed information.
- \* The organization list is sequenced according to alphabetical order.

Table III: Some government laboratories provided materials properties testing.

Organization	Phone #	Fax #	Address	website	M-E	C-A	M-E	NDE	T-P	Others
LHMEL	937-2556636	937-2520418	PO Box 33647, WPAFB, OH 45433						X	Thermal simulation
NASA-MSFC	256-5445746	256-5445892	MSFC/ET01, HUNTSVILLE AL 35812	<a href="http://nasa.gov/centers/marshall/home/index.html">nasa.gov/centers/marshall/home/index.html</a>						Propulsion, Environmental Testing, Structural Strength, Sturctural Dynamics
NASA-MSFC	256-5442725	256-5445877	MSFC/EM01, HUNTSVILLE AL 35812	<a href="http://nasa.gov/centers/marshall/home/index.html">nasa.gov/centers/marshall/home/index.html</a>	X	X	X	X	X	SEM and Failure Analysis, Hydrogen Testing, Surface Science Diagnositcs, Space Environmental Effects, Materials Combustion, Composite Development, Weld Development, Rapid Prototyping, Thermal Spray, Thermal Protection System Development
NASA-WSTF	575-524-5723	575-5245597	PO Box 20, Las Cruces, NM 88012	<a href="http://nasa.gov/centers/wstf/laboratories/">nasa.gov/centers/wstf/laboratories/</a>						Promoted combustion, Particle impact

**Notes:**

- \* M-T: mechanical testing, C-A: chemical analysis, M-E: metallurgical evaluation, T-P: thermal properties.
- \* Some (not all) of represented laboratories have provided fee-for-service for the related properties tests.
- \* Some DOE laboratories, such as Pacific NW Lab and Sandia National Lab, have the capability to perform all the related tests for their internal services (not fee-for-service base).
- \* The organization list is sequenced according to alphabetical order.
- \* Other promoted combustion test facilities: NASA-MSFC, Penn State, Air Products & Chemicals (PA), BOC (NJ), Praxair (NY).

Table IV: ASTM standards for the testing properties

Test Item	ASTM #	Test Title
Tensile	E8	Standard Test Methods for Tension Testing of Metallic Materials
	E21	Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials
	A370	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
	B557	Standard Test Methods for Tension Testing Wrought and Cast Aluminum and Magnesium Alloy Products
Compression	E9	Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature
Bending	E190	Standard Test Method for Guided Bend Test for Ductility of Welds
	E290	Standard Test Methods for Bend Testing of Material for Ductility
	E855	Standard Test Methods for Bend Testing of Metallic Flat Materials for Spring Applications Involving Static Loading
Young's modulus, shear modulus, Poisson's ratio	E111	Standard Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus
	E1875	Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio by Sonic Resonance
	E1876	Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio by Impulse Excitation of Vibration
	E143	Standard Test Method for Shear Modulus at Room Temperature
	E132	Standard Test Method for Poisson's Ratio at Room Temperature
Coefficient of thermal expansion	E228	Standard Test Method for Linear Thermal Expansion of Solid Materials With a Push Rod Dilatometer
Thermal conductivity	E1225	Standard Test Method for Thermal Conductivity of Solids by Means of the Guarded Comparative Longitudinal Heat Flow Technique
	E2584	Standard Practice for Thermal Conductivity of Materials Using a Thermal Capacitance (Slug) Calorimeter
Thermal diffusivity	E1461	Standard Test Method for Thermal Diffusivity by the Flash Method
Specific heat	E1269	Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry
	E2716	Standard Test Method for Determining Specific Heat Capacity by Sinusoidal Modulated Temperature Differential Scanning Calorimetry

Table IV: ASTM standards for the testing properties (continued)

Test Item	ASTM #	Test Title
Low/high cycle fatigue	E606	Standard Practice for Strain-Controlled Fatigue Testing
	E466	Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials
Fatigue crack growth rate	E647	Standard Test Method for Measurement of Fatigue Crack Growth Rates
Creep and Stress-rupture	E139	Standard Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
Fracture toughness	E1820	Standard Test Method for Measurement of Fracture Toughness
	E399	Standard Test Method for Linear Elastic Plane Strain Fracture Toughness $K_{Ic}$ of Metallic Materials
	E1304	Standard Test Method for Plane Strain (Chevron-Notch) Fracture Toughness of Metallic Materials
Metallography	E3	Standard Guide for preparation of Metallographic Specimens
	E112	Standard Test Methods for Determining Average Grain Size
Hardness	E10	Standard Test Method for Brinell Hardness of Metallic Materials
	E18	Standard Test Methods for Rockwell Hardness of Metallic Materials
	E384	Standard Test Method for Knoop and Vickers Hardness of Materials
Impact strength	E23	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials
Ultrasonic testing	E2375	Standard Practice for Ultrasonic Testing of Wrought Products
	A388	Standard Practice for Ultrasonic Examination of Steel Forgings
	E164	Standard Practice for Contact Ultrasonic Testing of Weldments
Wear testing	G65	Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus
Corrosion testing	B117	Standard Practice for Operating Salt Spray (Fog) Apparatus
	G85	Standard Practice for Modified Salt Spray (Fog) Testing
	G31	Standard Practice for Laboratory Immersion Corrosion Testing of Metals
	G50	Standard Practice for Conducting Atmospheric Corrosion Tests on Metals
Particle size distribution	B761	Standard Test Method for Particle Size Distribution of Metal Powders and Related Compounds by X Ray Monitoring of Gravity Sedimentation
Apparent density	B703	Standard Test Method for Apparent Density of Metal Powders and Related Compounds Using the Arnold Meter

Table IV: ASTM standards for the testing properties (continued)

Test Item	ASTM #	Test Title
Tap density	B527	Standard Test Method for Determination of Tap Density of Metallic Powders and Compounds
Specific surface area	B922	Standard Test Method for Metal Powder Specific Surface Area by Physical Adsorption
Particle morphology	F1877	Standard Practice for Characterization of Particles
Promoted combustion test	G124	Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen Enriched Atmospheres
	G88	Standard Guide for Designing Systems for Oxygen Service
	G94	Standard Guide for Evaluating Metals for Oxygen Service
	G63	Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
Welding*	NASA-STD-5006	General Fusion Welding Requirements for Aerospace Materials used in Flight Hardware

- Welding standard is N/A in ASTM standards, and NASA-STD-5006 is one of the alternatives.

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